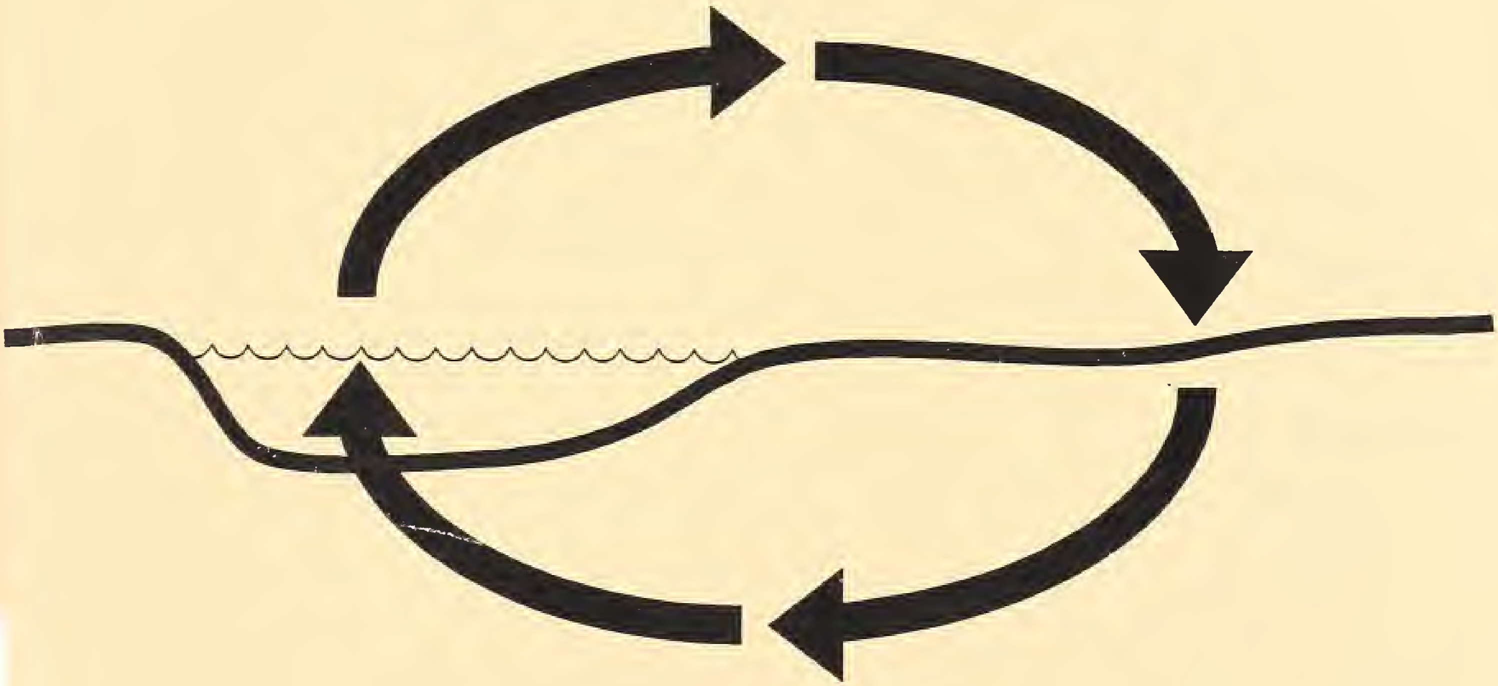
EVAPORATION IN AGRICULTURAL SYSTEMS: IMPLICATIONS FOR NATURAL RESOURCE ISSUES



NCR-160 Committee on Efficient Use of Water by Vegetation in Great Plains Environments

January 1992

The NCR-160 Committee on Efficient Use of Water by Vegetation in Great Plains Environments is sponsored by the North Central Region of the U.S.D.A. Cooperative State Research System. The committee is composed of University and U.S.D.A. scientists involved in water related research from the disciplines of micrometeorology, plant physiology, plant breeding, remote sensing, and soil physics. The committee was formed in 1988 as an outgrowth of the former Evapotranspiration and Remote Sensing Coordinating Committees of the Great Plains Agricultural Council. The purpose of the NCR-160 committee is threefold: 1) to develop cooperation and coordination among various agencies and institutions involved with research in evapotranspiration and efficient use of water; 2) to provide a forum for exchange of ideas among participating scientists; and 3) to sponsor workshops and symposia on relevant issues.

The ideas explored in this report were initially raised at the 1990 Annual Meeting of the NCR-160 Committee in a program entitled "The Hydrologic Balance: Evapotranspiration Research to Meet National Priorities and Needs." This program was developed because of the changing emphasis in many scientists' research programs from a single purpose production orientation to a broader natural resource management approach. Water management to maximize or optimize crop production is relatively simple. When issues such as water quality, agricultural sustainability, and global climate change are considered concurrently with crop production, many complex processes must be considered, some of which are not crucial when crop production is the primary concern. In many cases, these more recent research results have not been effectively communicated for implementation at the production and policy-making levels. This report was developed to communicate concern about these issues to research administrators, agency managers, and the general public.

This report was prepared on behalf of the group by an editorial committee consisting of Dr. Jerry L. Hatfield, U.S.D.A., Agricultural Research Service, Ames, IA; Dr. Donald C. Reicosky, U.S.D.A., Agricultural Research Service, Morris, MN; Dr. Jean L. Steiner, U.S.D.A., Agricultural Research Service, Bushland, TX; and Dr. Sashi B. Verma, Department of Agricultural Meteorology, University of Nebraska, Lincoln. Figures 1 through 3 were developed by Dr. Donald C. Reicosky. Figure 4 was adapted (by Dr. Jean L. Steiner) from "Research Needs for Efficient Use of Water by Plants in the Great Plains," 1985, Great Plains Agricultural Council Publication No. 114.

United States Department of Agriculture

Agricultural Research Service

Midwest Area
National Soil Tilth Laboratory

2150 Pammel Drive
Ames, Iowa 50011

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SUBJECT: Report from NCR-160 Committee

TO: Area Directors
Natural Resource National Program Leaders

FROM: J.L. Hatfield
Laboratory Director

Jerry L. Hatfield

Over the past 18 months the NCR-160 committee on "Efficient Use of Water by Vegetation in Great Plains Environments" has been assembling a white paper entitled "Evaporation in Agricultural Systems: Implications for Natural Resource Issues." This white paper is intended to raise several issues about the current state of knowledge and what future approaches should be taken in this research. We are hopeful that the concepts will generate some ideas and research activity in these areas.

We send you this paper for your information and welcome your feedback and comments.

Enclosure

Executive Summary

Water is critical to all life. However, clean water supplies are at risk in many regions due in part to modern agricultural practices. While our agricultural systems produce abundant food and fiber and contribute significantly to the GNP, high production levels have occasionally resulted in degradation of soil and water resources. Many current management practices do not adequately consider the complexities of the water cycle. Soil water content, which is largely a balance between precipitation and evaporation, influences all hydrological processes. Water is the transporting agent which moves chemicals from the soil surface into ground or surface water supplies or from soil reserves into plant roots. This report provides a framework for understanding the role of evaporation as a key hydrologic process and identifies areas where improved understanding or better implementation of existing knowledge can lead to more environmentally sound and sustainable management of our natural resources.

About 70% of precipitation over land in the USA evaporates without moving into water storage points such as streams or ground water. Most evaporation research has been conducted during cropping seasons, but evaporation during non-cropping periods is critical for understanding issues of water quality, agricultural sustainability, and crop productivity. Because water affects all biological activity and acts as a transport agent, soil water content is a key factor in carbon and nutrient cycles in agricultural ecosystems. Judicious manipulation of evaporation offers a great opportunity to control and conserve the soil water supply to optimize agricultural productivity and minimize environmental risks.

Evaluation of cropping system productivity and efficiency requires an integration of state-of-the-art knowledge from a wide range of disciplines. Temporal and spatial aspects of the soil surface properties affect infiltration, runoff, soil erosion, and water movement through the root zone in ways that are not yet completely understood. Many opportunities exist for managing plants as "pumps" to extract water and chemicals from the soil before they leach into ground water. There is also opportunity for conserving water through proper irrigation scheduling, use of plant residues, and other management techniques. Crop and tillage management influences surface soil water content and soil temperature and these in turn have a major effect on pesticide degradation, nitrogen cycling and uptake, and chemical transport. Water and nutrient use by one crop affects supplies for a subsequent crop, but we do not yet understand the requirements of many crops well enough to analyze the risks and benefits associated with cover crop or rotation systems.

Global climate changes may affect future temperature regimes and quantity and distribution of precipitation. To minimize adverse effects of possible climate change on agricultural stability, we need to understand how soil water and soil microclimate might respond to different scenarios of climatic change. We need to evaluate management changes which modify water use and crop productivity. In addition, we should integrate existing knowledge about water balance and evapotranspiration processes at local scales to larger scales to improve global climate models.

A multidisciplinary approach, utilizing the talents and expertise of many different scientific and management groups, is required to fully address issues such as

water quality, agricultural sustainability, and climate change. Farm-level decision making can be improved by utilizing cropping system models, but these models must be applicable at the field level. Economic and public policy evaluation, involving issues such as change in cropping practices and the commodity price support structure, water allocation schedules, and land use, requires models which can be applied at the regional and national level. Currently there is little coordination to ensure that field level and regional/national level models incorporate similar scientific knowledge about important processes in the hydrologic cycle. Development and implementation of needed models require improved communication and flow of technical information between researchers, managers, and policy makers.

FINDINGS:

Conservation tillage which maintains increased surface crop residue levels also changes runoff, evaporation, erosion, and soil temperature. Most soil water models do not adequately consider the effects of conservation tillage and surface residue on these hydrologic processes.

RECOMMENDATIONS:

Concerted efforts to understand and validate the soil water balance models which consider crop residue effects on evaporation, runoff, and erosion should be undertaken. These efforts should include development of data bases required for various tillage implements, soils, and crop rotations.

Crop, soil, and plant residue properties which affect evaporation are not well understood for sparse vegetative covers or for plants under severe water stress. Present models which predict crop water use do not perform well under these conditions.

Long term, coordinated, year-round evaporation studies need to be conducted in key climatic regimes for a wide range of vegetation and management practices to improve evaporation models and to extend them to a broader range of applicability, including severe water stress conditions. These models should then be applicable to water management in dryland and rainfed agriculture, as well as in irrigated agriculture.

Application of water through sprinkler irrigation is often inefficient with large losses due to soil water evaporation and evaporation from plant leaves. Most irrigation scheduling practices do not account for rainfall probability, and the current cropping practices consume large amounts of energy and nitrogen fertilizer that may degrade water quality.

Irrigation technologies and scheduling practices need to be developed which consider the crop growth stage, crop water requirements, crop fertilizer requirements, rainfall probability, and energy efficiency. Irrigation practices need to incorporate information on salinity levels and on crop response to stress.

FINDINGS:

Soil carbon is a large storage component in the global carbon balance. Soil organic carbon has decreased in most cultivated soils, but neither the magnitude of anthropogenic carbon loss to the atmosphere nor the potential to arrest or reverse this trend is known. Global carbon models do not adequately consider this component and are not presently interfaced with agricultural production models.

Evaporation, soil water flow, nutrient cycling, microbial dynamics, and pesticide degradation models have not been adequately linked to natural resource problems.

It is widely believed that leaching does not occur in the arid and semiarid regions; however, nitrates and pesticides have moved deep below the root zone in many dry regions.

Water is the primary limitation to plant growth, but few studies conducted on plant water relations have been done in soils under naturally stressed environments.

RECOMMENDATIONS:

The quantity of soil carbon and the rate of change of this component need to be measured, and the potential for and the impact of reversing the decline need to be evaluated. Information is needed on seasonal dynamics of carbon fixation by photosynthesis and carbon partitioning into the root system and ultimately into soil carbon.

Linkages need to be developed among the environmental component models and then the linked models need to be evaluated over a wide range of climates, soils, and management practices.

Research programs should be initiated to improve our understanding of the effect of the hydrologic cycle on water movement in the root and unsaturated zone across all climates and soils. Incorporating macropore flow and improving our understanding of unsaturated flow are required to improve natural resource models already in use.

Concepts regarding physiological response to water stress have been developed in the laboratory and in controlled environments and must now be extended to the field. Better understanding of plant water use when plants are stressed must be incorporated into evaporation models in conjunction with user models for crop management.

FINDINGS:

Rooting patterns are not understood in different tillage and cultural practices with regard to both spatial and temporal water and nutrient use patterns. Root water uptake patterns are further complicated by the distribution of water within the soil profile and need to be factored into root growth models.

Hydrologic processes which occur within the root and unsaturated zones from the fall to spring period are not well understood. Our understanding of physical and biogeochemical interactions during the crop season is extensive, less extensive during the noncrop season, and yet both are incomplete.

Soil biological activity is dependent upon the dynamic soil water balance; however, incorporation of these dynamics into soil biological studies has been lacking.

Much of the water in the hydrologic cycle is returned to the atmosphere through plant water evaporation. It is believed that plants could be used effectively as systems for managing the water and nutrient movement through the soil profile during the off-season.

RECOMMENDATIONS:

An understanding of the interactive effects of tillage and cultural practices on rooting patterns and water and nutrient use patterns needs to be developed in different soils and climates as a basis for sustainable agriculture.

Long term studies in different soils in the continental climates are needed to develop an understanding of the water and water vapor movement through the soil under freeze-thaw cycles and the implications of these processes on nutrient movement, nutrient cycling, and pesticide degradation throughout the crop and noncrop seasons.

Expertise in soil biology needs to be incorporated into studies evaluating the effect of tillage and cultural practices on the soil water balance.

Research programs are needed to address the limitations of managing the soil water balance and the chemical movement in the root zone through the use of deep-rooted plants and cover crops.

FINDINGS:	RECOMMENDATIONS:
There is limited understanding of the interaction between the transfer of water vapor to the atmosphere and the movement of radiatively important trace gases in agricultural production systems.	Theoretical and experimental studies need to be designed and implemented which incorporate the interaction of water vapor and radiatively important trace gas movement into the atmosphere. These studies need to interface with global climate change studies.
Regional estimates of evapotranspiration are limited by the lack of data bases and techniques that effectively utilize remote sensing information. The complex interaction of spatial and temporal variability further complicates accurate estimates of evapotranspiration.	A concerted effort is needed to develop and evaluate regional estimates of field scale precipitation and evaporation through a combination of current technology. Field specific information and decision aids are needed to enable individual managers to make environmentally sound decisions.
There is a time lag in transferring technology and adapting scientific findings to regional and national policy issues.	Improved communication is needed among agencies to develop a clearer understanding of the needs and requirements of the client and to develop an infrastructure for incorporating research findings more quickly into policy issues.

I. Introduction

Water is critical to society; the need for clean, abundant supplies of the life-sustaining fluid should dictate how this resource is used and allocated. The hydrologic cycle, which determines the quantity and timing of water availability, is simple to understand: water which falls as precipitation enters the soil or runs into rivers, lakes, or oceans, it returns to the atmosphere through direct evaporation or plant transpiration, and then cycles again. The variability and complex interactions of hydrologic processes and their influence on natural resource issues, on the other hand, are not so easily understood. The intent of this essay is to provide a framework for understanding the role of evaporation as a key hydrologic process (Fig. 1) and to identify areas where improved understanding or better implementation of existing knowledge can lead to more environmentally sound, sustainable management of our natural resources.

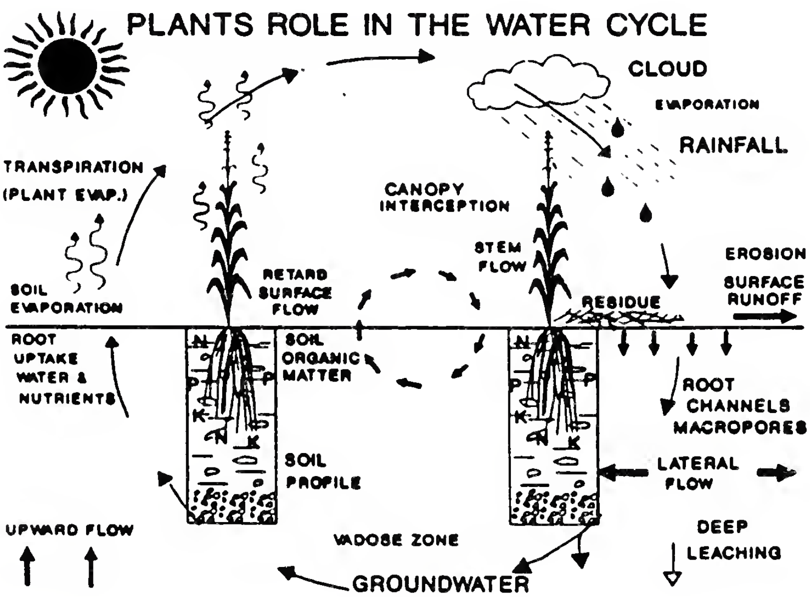

Figure 1. The hydrologic cycle showing the key roles of plants in hydrologic processes.

The presence of large oceans leads to the perception that we have an abundant supply of water. However, the main sources of fresh water in lakes, rivers, ground water, and the atmosphere, make up less than 1% of the earth's water supply (2, 10). In recent years, there has been increasing concern about the quality and safety of fresh water supplies. This concern has been prompted by reports of organic and inorganic materials in surface and ground water samples (10). There is also concern, particularly in arid and semiarid regions, about the ability of the hydrologic cycle to supply society's needs for water during major drought periods.

Agricultural systems constitute a major land use; in most countries food and fiber production constitutes a large portion of the GNP. In the United States, high production has occasionally resulted in the degradation of soil and water resources. Current USA management practices do not adequately consider the complexities of water movement within an agricultural system. With increasing world population, there is a need to balance the requirements for food and fiber production against the need for a sustainable and safe environment. Crop production for export is critical to meet the world food needs. We need to understand hydrologic processes at the agricultural system scale and to explore new management methods to improve and maintain the quality of our fresh water supply.

II. The Evaporation Process

Evaporation is an important component of the hydrologic cycle. About 70% of precipitation over land evaporates locally, without moving into storage bodies. Some evaporation occurs directly from the soil surface, water surfaces, or wetted plant surfaces, while the majority of the water moves into the soil and is taken up

by plant root systems and transported to leaves where transpiration occurs (Fig. 1). The process of evaporation converts liquid to vapor. Water vapor is easily transported to the atmosphere where it is converted to a liquid or a solid and returns to earth. Evaporation and transpiration also modify near-surface temperatures due to the large amount of energy consumed in vaporizing water. Evaporation is driven by atmospheric conditions (e.g. solar radiation, temperature, humidity, wind) and water availability, with both factors contributing to the dynamic nature of the process. Because of the seasonality of these controlling factors, we can identify periods in which there is a high risk of rapid runoff or rapid movement through the soil profile which could carry contaminants into water supplies. The seasonal variation of precipitation and soil water supply, along with variability in soils and topography, complicates the development of improved management practices which might minimize environmental risk and improve water and nutrient use efficiencies by plants. There have been numerous attempts to predict evaporation rates with equations. The equations range from those based on monthly temperatures to physically-based equations which require a variety of daily or hourly inputs. A variety of commonly-used equations have been described and evaluated in recent reports (4, 7, 8). The equations have been developed and validated using direct experimental measurement.

Agricultural water balances are often studied only during the crop growing season. Such studies rarely extend over the entire year or across multiple years. Year-round studies at the field or watershed level over several years are required to solve certain complex problems. A primary limitation to our current knowledge about evaporation is the inability to isolate and quantify surface processes such as runoff, infiltration, and water flow in soils at scales larger than uniform fields. For large regions, we are, as yet, unable to quantify the factors which control the

processes such as variable slope and surface relief, variability in surface soil water content, variability in vegetation cover, and variability in soil properties which control flow rates in soil. This prevents extension of evaporation estimates to larger spatial and temporal scales (3).

III. National Water Management Issues and Strategies

A. Water Quality

Some of the nation's drinking supply contains nitrates and pesticides; however, a direct association between specific agricultural management practices and water quality has not been clearly established. Pesticides and nitrates move below the root zone when crops and soil microflora do not extract or eliminate them from the root zone. Flow rates are faster through a wet soil profile than through a dry profile. Large pores in soils, such as root channels or worm holes, will change the flow processes and may increase the risk of chemical loss because of more rapid water flow deep into the profile. Alternately, the large pores may reduce risk of leaching because the water flow from the surface bypasses much of the soil zone where chemical concentrations are high. The microbial transformation and soil adsorption processes for agricultural chemicals are not yet completely understood. Microbiological activity and chemical transformations are influenced by the soil water content and soil temperature. Transformation and transport processes within the unsaturated zone are not fully understood and require further research. Because water affects biological activity and acts as a transport agent, soil water content is a key factor in carbon and nutrient cycles (Fig. 2).

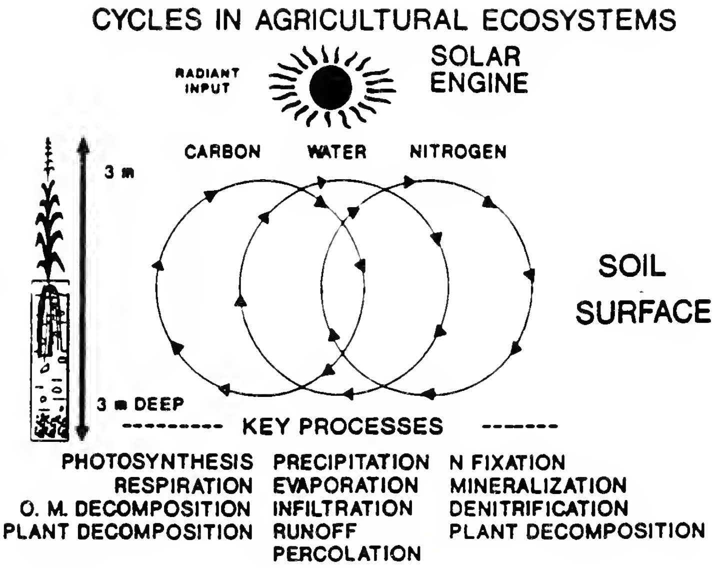

Figure 2. Interactions of the water, carbon, and nitrogen cycles controlling processes at the earth's surface.

Areas in which information is needed include the following:

1. Soil surface properties which change over space or time and affect infiltration, runoff, soil erosion, and evaporation;

2. Soil water and chemical movement within the root zone including preferential flow processes (macropores);

3. Managing plants as "pumps" to tie-up or withdraw water and chemicals from the soil profile before they leach into ground water supplies; and

4. Influences of management practices (e.g. tillage, fertilization, pesticide applications, cropping systems) on soil biological activity, pesticide degradation, nitrogen cycling and uptake, chemical transport, soil erosion,

and water use.

Selected scenarios illustrate management influence on water quality. Scenario one involves a wet soil profile where downward movement through the profile is rapid. Saturated or near saturated soil water profiles typically contain high levels of nitrates and other chemicals in solution. Thus, water added to the surface can rapidly transport the chemical-laden solute below the root zone. Since the soil profile can not hold any additional water, water applied at a high rate will result in a large amount of surface runoff to streams and recharge areas. This situation occurs in spring in much of the Midwest where the soil is often saturated when rains commence. It may be possible to shape the soil surface through tillage to channel the water past concentrated zones of applied chemicals, e.g., by banding nitrates and pesticides on the top of ridges.

Scenario two involves a dry soil profile. In this case, the soil may be able to accept and maintain high rates of water infiltration over an extended time period. Chemicals in the soil are not expected to move below the root zone because there is less water flow to transport the solutes. However, water drainage below the root zone has been measured in very dry climates. Considerable amounts of nitrate have leached below the root zone in many Great Plains soils following the initial plowing of the prairies from the native grass system. The processes by which water and chemicals move downward in dry soils are often overlooked and are not well understood. Many soil water balance models, widely used for agricultural simulations, do not predict the water and nitrate leaching which have occurred.

Throughout the growing season, both scenario 1 and 2 occur regularly. In irrigated

fields there is opportunity to manage the soil water content in a manner which minimizes leaching below the root zone. This can be accomplished by maintaining a partially dry soil profile to accommodate water from precipitation. Irrigation could be judiciously used to minimize risk of excessive crop losses during dry periods. In arid regions, however, salt buildup can become a problem if periodic leaching is eliminated, and this complicates soil water management considerably.

In some climates, it may be possible to increase plant water use to maintain a drier soil water content, to minimize surface runoff, and to reduce leaching. Use of cover crops can be critical to control soil water levels and to immobilize nitrogen during the non-growing season of the main crop (Fig. 3). Inorganic nitrogen uptake by nonleguminous cover crops is in the range of 10 to 75 lb. N/ac. depending on the species and climate. Experiments in Iowa illustrate problems in managing water and nitrogen balances without a cover crop. Soil water content and soil nitrogen levels were high in the spring. Nitrate concentrations in water collected from tile flow drains were high at the beginning of the corn growing season and only decreased during grain filling. Nitrates from decomposing corn residue resulted in high nitrate levels in the drainage water soon after harvest (J.L. Hatfield, unpublished data).

To effectively utilize cover crops, we need to understand the amount of water and nitrate which the cover crop extracts from the soil, the effect of water extraction on movement below the root zone, and the availability of water and nutrients to a subsequent crop. To be effective, cover crops need to have high extraction capacity for water and nutrients, but they can excessively reduce water and nutrient supplies for the subsequent crop.

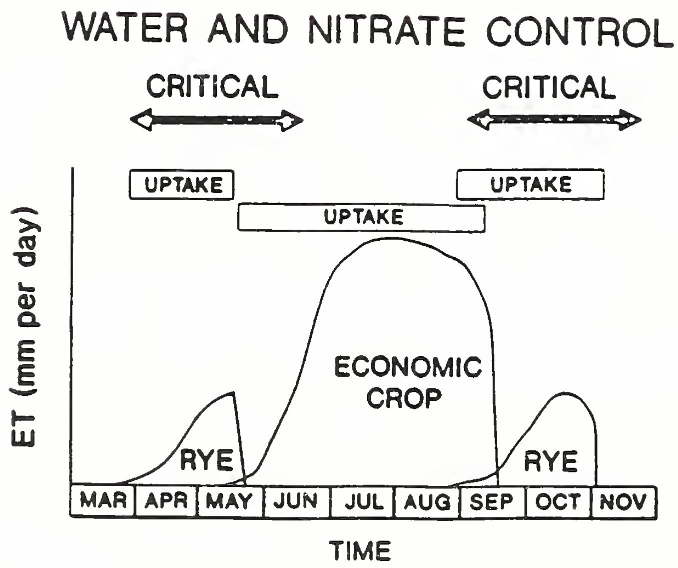

Figure 3. Using a cover crop to control uptake of water and nitrates during the non-growing season of the primary economic crop.

Understanding the seasonal dynamics of evaporation and precipitation is required to predict the effect of a change in cropping practice or surface management on water quality. Evaporation models have primarily been developed and tested during crop growing seasons and their applicability during the remainder of the year needs to be determined. Considerable effort is also needed to improve and validate these models for realistic and accurate application at the field and watershed level. Evaporation models must be coupled with pesticide fate and transport models and with nutrient cycling models in order to fully evaluate the implications for management changes on surface and ground water quality. Efforts to develop models and decision support systems to improve pesticide and nutrient management at the field, farmstead, watershed, "hydrologic unit," and the SCS "major land resource area" scales are underway as part of the USDA Water Quality Initiative.

B. Sustainable Agriculture

The goal of sustainable agriculture is to develop agricultural systems which are environmentally and economically sound. These systems require a thorough understanding of crop productivity and seasonal water and nutrient use patterns. Sustainable agriculture often is based on crop rotations, so long term studies over a number of the rotation cycles are required.

Questions related to the role of evaporation in agricultural sustainability include the following:

1. How does agronomic management (e.g., crop residue, tillage, irrigation management, and surface configuration) affect evaporation and the availability of water to plants?

2. How does crop rotation influence seasonal and yearly water balances? How do water and nutrient use from one crop affect supplies for the subsequent crop?

3. What physiological responses affect plant productivity under limited water supplies? How can relevant ecological principles be used to improve the competitive nature of crop plants in monoculture and in mixed cropping?

4. How does the plant root structure, density, distribution, and physiology affect the availability of soil water, the rate of stress onset, and the intensity of stress?

Changing crop residue management will affect soil water evaporation rates and thus water storage. Additional surface residue increases and maintains infiltration rates. Increased infiltration should reduce sediment losses and improve the water balance of agricultural lands; but in wet climates, it may increase the risk of nitrate and pesticide leaching. Surface crop residues have primarily been studied in small plots and need to be extended to field and watershed scales.

Development of sustainable agricultural systems requires maximizing plant water and nutrient use efficiencies. Evaluation of cropping system productivity and efficiency requires models which integrate knowledge from physical and biological disciplines (Fig. 4). Many processes in such integrated models are dependent upon soil water content which can only be accurately modeled if evaporation is accurately estimated. Evaporation models which incorporate key physical and biological principles require estimation of the surface resistance to vapor flow. Surface resistance for well-watered, full-cover crops can be approximated relatively easily (1). However, for application to sparse-cover crops, the soil and residue influences need to be better described. As plants undergo stress, the crop resistances to water vapor losses are not well quantified. The surface resistance approach should be evaluated over a wide range of rainfed conditions to broaden its applicability.

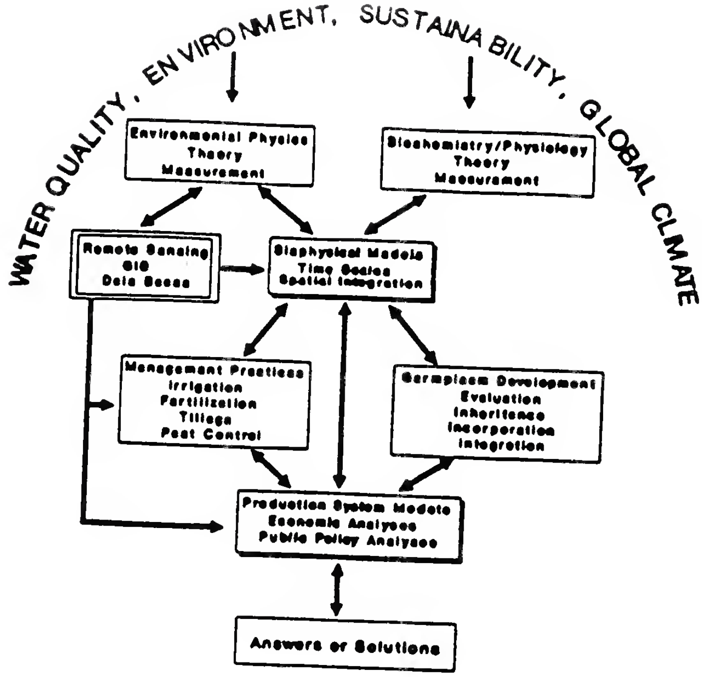

Figure 4. Interactions of basic and applied sciences by incorporation into process-oriented research and production system models.

In the western Great Plains, irrigated areas are prime crop production areas. Water supplies for irrigation are limited by declining ground water reserves and by the cost of pumping from deep water levels. Sustainability requires adequate water use to assure economic crop yields, as well as efficient water application and use by plants. Minimizing non-productive evaporation is required in irrigated agriculture, just as it is in rainfed production.

Irrigation efficiency can be improved by reduced conveyance losses, runoff, frequency or extent of soil surface wetting, and evaporation losses from overhead sprinklers; improved irrigation timing to meet the most critical crop water needs; and limited or deficit irrigation practices. Risk increases with limited irrigation and poses problems for implementation. Sustainability requires that agronomic risk be reduced without greatly increasing water or energy requirements.

Reducing nonproductive evapotranspiration is a point of attack for both furrow and center pivot irrigation management. Center pivot sprinkler systems are attractive because they have low labor requirements compared to furrow irrigation. They can be designed to have relatively low energy requirements if low water pressure levels are used, although lower pressure generally results in increased runoff problems. Both center pivot and furrow irrigation systems can be adapted to limited irrigation management.

Additional questions related to irrigation include the following:

1. How can irrigation technologies and management be changed to minimize wetting the soil surface while supplying the crop needs?

2. How can the energy and labor requirements for irrigation be reduced?

3. How can conjunctive use of rainfall and irrigation water minimize irrigation requirements over a season?

On-farm management decisions require that models be accurate at the field level over a wide range of soil and climate conditions. Some inputs for such models can come from automated weather stations which are beginning to cover much of the Midwest or from weather generators which derive the daily parameters from mathematical simulations. The High Plains Climate Center weather network and the California Irrigation Management Information System are examples of automated systems which can supply the needed climate data for such models. Precipitation is so variable over time and space that it should be measured at each field for real-time management applications and in dense networks for regional

assessments.

An important consideration for estimating the water requirement over a large region encompassing agricultural production is the ability to estimate evaporation for the region. As evaporation in some components of the region increase (e.g. irrigated fields in a desert region), the evaporative demand for the whole region declines because of the cooling and humidifying effect of the atmosphere associated with irrigated fields. It is difficult to adequately measure subregion climate and evaporation within a region to accurately sum up regional evaporation. An alternative approach might be to divide the region into subregions using remote sensing techniques and geographical information systems (GIS) and then to model evaporation in each subregion. For this to work, climate in each subregion must be measured to account for the effect of evaporation in one subregion on the potential evaporation of other subregions, or the models would have to simulate interactions of the surface and the atmosphere among subregions. These interactions and processes are difficult to model at large scales. In the 1970's, joint ventures between NASA and agricultural scientists, micrometeorologists, and hydrologists led to improved understanding of remote sensing techniques for vegetation and land assessment. Further collaboration should yield improved understanding and modeling of regional evaporation processes.

In many regions of the USA, deficient water will remain a primary limitation to production. Competition for water for urban uses, for industry, and for protecting critical environmental areas will continue to increase. In water-deficient regions, emphasis on water conservation and water use efficiency will continue. Current public policies do not adequately deal with allocation of limited water resources and new approaches are required (5).

C. Climatic Change

Climatic change, potentially resulting from the increasing concentration of atmospheric trace gases (such as carbon dioxide, methane, nitrous oxide, etc.), may alter the temperature regime and the quantity and distribution of precipitation. The exact changes and the magnitude of the changes within USA regions are difficult to predict. Since water availability and distribution dictate the type and growth of crops, a significant change in climate may require a change in the crop type. Changes in management practices which could improve the stability of the soil water resource under conditions of increased variability of precipitation and changing evaporation rates may be required.

Several questions related to the role of evaporation and climatic change include the following:

1. What changes would occur in the soil water and soil microclimate patterns under different scenarios of climate change?

2. How can changes in the surface configuration and crop management alter the rate and amount of water use and crop productivity under drier or warmer environments?

3. How do photosynthesis, stomatal conductivity, and water use efficiency change under increased CO_2 levels in various water regimes? How do the increasing concentrations of other atmospheric trace gases affect these relationships?

4. How can evaporation models utilizing field level soil and crop parameters be integrated to larger scales and used to improve general circulation models?

Addressing these questions will require a multidisciplinary and concentrated research effort. If the predicted changes in precipitation (±20%) and predicted intraseasonal variability (+50%) occur, then the seasonal water balance would change over large areas (such as the Great Plains, the Midwest Cornbelt, the irrigated West, the Southeast). This would have serious implications for crop management.

In most global circulation models, evaporation is calculated at a minimum grid size of about 1° latitude, often using a monthly time-step. There is a wide discrepancy in the spatial and temporal resolution of these models, compared to those developed for smaller areas. Current state-of-the-art evaporation and soil water balance models have not been utilized in global level models and additional research and development is required before incorporation. Improved evaporation and soil water balance models could improve global models because evaporation accounts for a large percentage of the solar energy use. The hydrologic cycle and the availability of solar energy drive the global climate.

Decreased precipitation would reduce the amount of water available for evaporation and for recharge of streamflow and ground water. If loss via soil water evaporation could be minimized, then more water could be stored in the soil for later crop use. In many irrigated regions, alternative cropping systems and improved irrigation design and management are needed to reduce water requirements.

In the current climatic change scenarios, the soil surface and air temperature would tend to be warmer and the atmospheric demand for plant transpiration would be increased. Research suggests that either water use efficiency by plants will increase because of increased photosynthesis at higher CO_2 concentrations or that transpiration will decrease due to partial stomatal closure at higher CO_2 levels. If we are to understand how to stabilize crop production under situations of a changing climate, various microclimatic-physiological relationships must be better understood. Water conservation measures, such as residue management, should help achieve maximum water use efficiency.

Observations from Hawaii show that atmospheric CO_2 increases in summer and decreases in winter because of seasonal variations in plant growth (9). Since plant growth extracts large amounts of CO_2 from the atmosphere, carbon storage in vegetation is one way to slow the increase of atmospheric CO_2 levels. This concept underlies efforts to reduce deforestation and increase tree planting. Storing carbohydrates in soils via root systems may also reduce the carbon dioxide levels in the atmosphere. Globally, particularly in semiarid regions, there have been tremendous losses of soil organic carbon when native vegetation is replaced by agricultural systems. However, the changes in regional or global quantities of soil carbon storage have not been studied in detail. If the carbon content of soils is increased, there is a general improvement in soil quality due to reduced runoff, reduced soil erosion hazard, increased soil biological activity, and improved nutrient availability.

IV. Communication Needs

A. Interdisciplinary Ties

The problems which have been described can not be solved by any single scientific discipline. Close cooperation of policy makers, the general public, and academic staff is required. A multidisciplinary approach that combines the talents and expertise of many different relevant groups is required to fully address the issues. Some of the many disciplines which are needed include soil science, agronomy, ecology, plant physiology, microbiology, chemistry, meso- and micro-meteorology, climatology, hydrology, economics, and engineering. The linkages among these disciplines depend on the problem being studied. Geographical information system (GIS) technology offers possibilities for scaling information along both temporal and spatial lines. Remote sensing technologies will be required to interface with GIS technology to collect some of the inputs required to apply large-scale models to regions such as the Cornbelt or the Great Plains.

B. Public Policy and Economics

Issues facing the agricultural community, such as water quality, sustainability, and climatic change, are critical to broad international policy and economic decisions. An integral part of such decisions is risk analysis. Economic and policy aspects are seldom considered in agronomic studies. Public policy issues which need to be addressed by researchers include changes in cropping practices and the commodity price support structure, water allocation schedules, and land use as they influence environmental quality. To evaluate policy issues requires either adaptation of current models or development of new models to describe production and

management at the national level.

Economic analyses must be incorporated into farming systems' studies. Without such cooperative studies, research results may not be extended to a farm or community scale. Incorporation of economic analyses into research studies will provide new insights into possible changes of the agricultural system. To accomplish this task will require a technical integration between researchers and policy makers of the agricultural and ecological system (Fig. 4).

V. Conclusions

Many challenges facing agriculture's use of water require improved information about evaporation processes. The current issues of water quality, sustainable agriculture, and climatic change require a new understanding of the complexities and interactions of the hydrologic cycle and food production. Evaporation accounts for about 70% of local water loss, so strategic manipulation of evaporation offers the opportunity to control soil water supply and soil erosion to provide adequate water for crop production while minimizing environmental risks. Questions raised in this brief report should encourage the variety of research needed to provide the basic information that will address these issues.

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